PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 :		(11) International Publication Number:	WO 90/13130
G21B 1/00	A1	(43) International Publication Date:	1 November 1990 (01.11.90)

(21) International Application Number: PCT/US90/01990

(22) International Filing Date: 12 April 1990 (12.04.90)

(30) Priority data:

338,705	13 April 1989 (13.04.89)	US
338,706	14 April 1989 (14.04.89)	US
340,051	18 April 1989 (18.04.89)	US
340,951	20 April 1989 (20.04.89)	US
366,890	15 June 1989 (15.06.89)	US

(71)(72) Applicant and Inventor: LO, Shui-Yin [AU/US]; 3649 Woodcliffe Road, Sherman Oaks, CA 91403 (US).

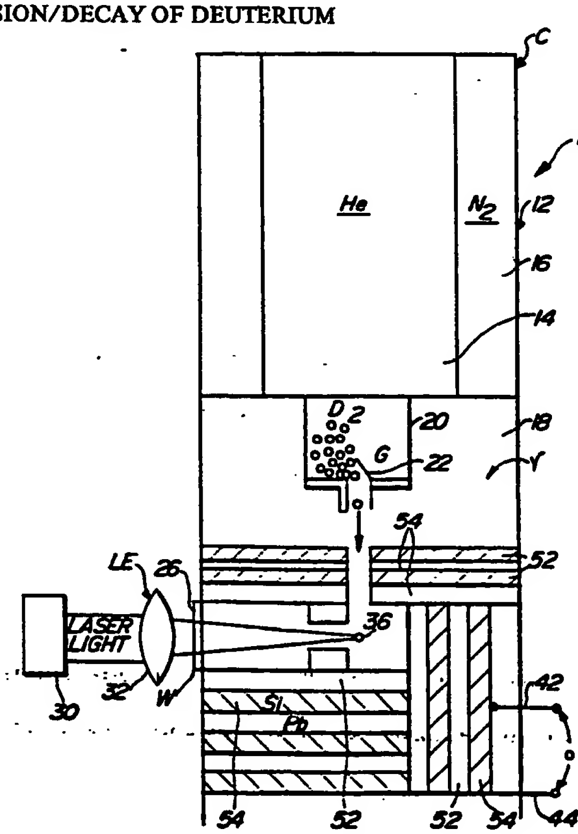
(74) Agents: GALLENSON, Mavis, S. et al.; Ladas & Parry, 3600 Wilshire Boulevard, Suite 1520, Los Angeles, CA 90010 (US).

(81) Designated States: AT, AT (European patent), AU, BB, BE (European patent), BF (OAPI patent), BG, BJ (OAPI patent), BR, CA, CF (OAPI patent), CG (OAPI patent), + CH, CH (European patent), CM (OAPI patent), DE, + DE (European patent), DK, DK (European patent), ES, ES (European patent), FI, FR (European patent), GA (OAPI patent), GB, GB (European patent), HU, IT (European patent), JP, KP, KR, LK, LU, LU (European patent), MC, MG, ML (OAPI patent), MR (OAPI patent), MW, NL, NL (European patent), NO, RO, SD, SE, SE (European patent), SN (OAPI patent), SU, TD (OAPI patent), TG (OAPI patent), US.

Published

With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: ENHANCED FUSION/DECAY OF DEUTERIUM



(57) Abstract

A method of enhancing the decay/fusion rate of bosons which have a mass, comprising forming of cold plasma of these bosons by impinging these bosons with a strong pulse of high energy bosons from a boson source (30).

+ See back of page

DESIGNATIONS OF "DE"

Until further notice, any designation of "DE" in any international application whose international filing date is prior to October 3, 1990, shall have effect in the territory of the Federal Republic of Germany with the exception of the territory of the former German Democratic Republic.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria	ES	Spain	MC	Monaco
AU	Australia	FI	Finland	MG	Madagascar
BB	Barbados	FR	France	ML	Mali
BE	Belgium	GA	Gabon	MR	Mauritania
BF	Burkina Fasso	GB	United Kingdom	MW	Malawi
BG	Bulgaria	GR	Greece	NL	Netherlands
BJ	Benin	HU	Hungary	NO	Norway
BR	Brazil	IT	Italy	RO	Romania
CA	Canada	JP	Japan	SD	Sudan
CF	Central African Republic	KP	Democratic People's Republic of Korea	SE	Sweden
CG	Congo			SN	Senegal
CH	Switzerland	KR	Republic of Korea	SU	Soviet Union
CM	Cameroon	LI	Liechtenstein	TD	Chad
DE	Germany, Federal Republic of	LK	Sri Lanka	TG	Togo
DK	Denmark	LU	Luxembourg	US	United States of America

ENHANCED FUSION/DECAY OF DEUTERIUM

I. Background

It is known in the art to direct laser beams against solid deuterium and obtain some reaction at a very low decay rate. This invention, through the manipulation of deuterium density and temperature, laser pulsing and power accomplishes a very large and powerful decay rate.

It is well known in the theory of strong coupling plasma, screening due to electrons reduces considerably the Coulomb barrier among positively charged ions. This is discussed in "In Introduction to Statistical Physics of Charged Particles," by S. Ichimaru, Plasma Physics, Benjamin/Cummings (1986) p. 193; and in "Strongly Coupled Plasma Physics, by F.J. Rogers and Hugh E. Dewitt, Plenum 1987, and references therein. Nuclear fusion among the ions is greatly enhanced by an exponential factor $A = \exp(1.25\ \Gamma_p)$ where $\Gamma_p = P.E./K.E. = e^2/aT$ is the coupling of the plasmà, a, and T being the distance between the ions and temperature of the ions respectively. The limit of strong coupling $\Gamma_p \to \infty$ as $T \to o$ is coherence. In astrophysical condition, nuclear reaction is found to be greatly enhanced in the interior of a star. For example, carbon plasma with temperature $T = 10^8$ °k, and a density $10^9 gm/cm^3$, the enhancement factor A becomes 3×10^{80}. There is therefore indirect evidence that enhancement of nuclear fusion occurs in hot strongly coupled plasma.

II. Summary of Invention

Disclosed herein is a method of forming strongly coupled to coherent bosons with mass (B) in a cold plasma by cooling the bosons with mass (B) at least to room temperature and shining thereon in a short, high intensity pulse so as not to cause the plasma to become hot, a beam of strongly coupled to coherent bosons (b), the energy of said bosons (b) being greater than the ionization energy of the bosons with mass (B).

III. Theoretical Background of Invention

Recently the production of coherent pions in high energy scattering processes has been well studied in C.S. Lam and S.Y. Lo, Phys. Rev. Lett. 52, 1184 (1984); ibid Phys. Rev. D 33, 1336 (1986); International J. of Modern Phys. VI, 451 (1986) incorporated herein by reference, and there exists some experimental evidence as noted in S.Y. Lo and A. Schreiker, Phys. Lett.B171,475 (1986); S.Y. Lo, Phys. Lett.186, 416(1987), with earlier references cited in those papers, incorporated herein by reference, for such coherent pions. Coherent pions, however, are only produced microscopically in small numbers, and hence are of no practical use. In analogy with laser, it is argued that stable charged nuclei such as α-particles and deuterons can be made to become coherent by inducing scattering as discussed in my international patent application PCT/AU86/00212 incorporated herein by reference. However charged nuclei, quite unlike photons, are

not neutral and interact strongly. Whereas photons can propagate unimpeded in media like glass and air and so can be made coherent in a gradual way by adding one photon at a time, charged nuclei will interact strongly with any media. Therefore, greater complications are expected if we want to create strongly coupled or ultimately coherent charged nuclei in a gradual way like coherent photons created in a laser tube. It would be best if a process is found whereby charged nuclei can be created coherently in an instantaneous fashion so that there is no need for them to travel in any media. Such an instantaneous process is in fact possible.

A) Ionizing a Deuterium Atom -- Broad Overview

From a straightforward extrapolation, one may expect perhaps an infinite enhancement of nuclear fusion for a plasma with infinite coupling. Explicit Monte Carlo calculation has shown that the exponential enhancement factor is at least valid to $\Gamma_p \leq 160$. For a fusion rate of $\Gamma_0 = 10^{-70}$ sec, for two deuterons separated by 0.72°A, it will be enhanced to a rate $\Gamma_1 = 1/\text{sec}$ for $\Gamma_s = 161$. For discussion, we could use this value of 161 as a minimum value to calculate the additional quantum effect. If the limit of infinite coupling is approached from the low temperature side ($\Gamma_s \rightarrow \infty$ as $T \rightarrow 0$), then there is in addition quantum effect to be considered due to the compton wave length λ_c of the ion $1/\sqrt{T}$ becomes infinite as temperature approaches zero, $T \rightarrow 0$. When $\lambda_c \rightarrow \infty$, the ions become coherent. This is similar to liquid helium becoming superfluid

helium which is coherent at low temperature. Liquid helium becomes superfluid at T = 2.17°K. Hence, we do not expect to need T = 0 or infinite coupling to have coherent deuterons in reality. From theoretical discussion here, it is perhaps convenient to stay at the idealized limit of $T \to 0$, $\Gamma_p \to \infty$. The calculation of interaction involving coherent bosons has been well studied in the study of coherent pions in high energy scattering discussed in the above referenced 52, 1184(1984) Phys. Rev.

Let us consider the elementary process of ionizing a deuterium atom (D) by one energetic photon (γ) to become a deuteron (d) and an electron (e):

$$\gamma(\vec{k}) + D(\vec{p}) \to e^- (\vec{q}) + d^+(\vec{p}') \qquad (1)$$

where $\vec{k},\vec{p},\vec{q},\vec{p}'$ are momenta of the particles γ,D,e,d, respectively. The effective Hamiltonian interaction for the ionization process (1) is given by

$$H_I = g \int d^3 x \; (A \Psi_D \Psi_e^{\dagger} \phi_d + \text{h.c.}) \qquad (2)$$

where Ψ_D, Ψ_e, Φ_d, A are the quantum fields of deuterium (D), electron (e), deuteron (d) and photons respectively. All spins are neglected. The effective coupling (g) can be evaluated from the ionization cross section:

$$\sigma_I = g^2 \mu (V_\gamma V_D / V_e V_d)^{1/4} \quad (2\mu \; (\omega + \vec{p}^2/2m - \varepsilon_D))^{1/2} \quad /2\pi\omega \qquad (3)$$

where μ, m are the masses of electron and deuteron, ω the energy of the photon, and ε_D is the ionization energy of the deuterium atom. The normalization volumes $V_{\gamma,D,e,d}$ for the four different

particles γ ,D,e,d are given by conditions in the experiment. When the deuterium atom is embedded in a solid block of deuterium, there is a distribution in momentum (p) due to the finite temperature. The transition rate for (1) to happen has to be averaged over the initial momentum distribution of the deuterium atoms.

$$\overline{w}_1 = \sum_{\vec{p}\vec{q}} 2\pi\delta\ (\Delta E)\ |\langle\vec{p}'\vec{q}|\ H_I\ |\vec{p}\vec{k}\rangle|^2\ N(p) \qquad (4)$$

where $\delta(\Delta E)$ is the Dirac δ-function with ΔE equal to the difference in energy of initial and final state. This δ-function ensures energy conservation.

The distribution (N(p)) is assumed to be Maxwellian:

$$N(p) = (2\pi)^3/V_D \quad (2\pi m\ \ k_B T)^{3/2}\ e^{-p\ /2mk_B T} \qquad (5)$$

where k_B is the Boltzmann constant, and T the temperature. Then the averaged rate is

$$\overline{w}_1 = g^2\mu m k_B T[N(p_o)-N(p_1)]\quad [4\pi\omega|\vec{p}'-\vec{k}|\sqrt{V_\gamma V_d}]^{-1} \qquad (6)$$

where p_o, and p_1 are the limits of the values of momenta that the initial deuterium D(p) can have from conservation of energy-momentum so as to produce the same final momentum of deuteron p'.

$$p_o = \left|\ |\vec{p}'-\vec{k}| - [2\mu(\omega - p'^2/2m - \varepsilon_D)]^{1/2}\right|$$

$$p_1 = |\vec{p}'-\vec{k}| + [2\mu(\omega - p'^2/2m - \varepsilon_D)]^{1/2} \qquad (7)$$

We are interested in producing all deuterons in the same quantum state, out of all the possible final states, which is given by $^1/\eta$:

$$1/\eta = \frac{2\pi}{\tau}\sum_{\vec{p},\vec{q}} N(p)\,\delta_{\vec{p}+\vec{k},\vec{p}'+\vec{q}}\;\delta\Big(\omega+\frac{\vec{p}^2}{2m}-\varepsilon_D-\frac{\vec{p}'^2}{2m}-\frac{\vec{q}^2}{2\mu}\Big)$$

$$= \frac{1}{\tau}\sqrt{V_e/V_D}\;\frac{\mu}{|\vec{p}'-\vec{k}|}\;\Big(\frac{2\pi}{mk_BT}\Big)^{\frac{1}{2}}\;\Big(e^{-p_0^2/2mk_BT}-e^{-p_1^2/2mk_BT}\Big) \qquad (8)$$

where τ is the characteristic time of interaction during the scattering process. The probability of (1) to occur is

$$P_1 = 1/4W_1\tau \qquad (9)$$

Let us now consider the simultaneous ionization of n deuterium atoms in a solid at low temperature by n coherent photons such as found in a laser beam:

$$n\gamma(\vec{k})+D(\vec{p}_1)+\ldots D(\vec{p}_n)\rightarrow nd^+(\vec{p}')+\ldots e^-(\vec{q}_1)+\ldots.e^-(\vec{q}_n) \qquad (10)$$

with the production of n coherent deuterons with the same momentum p'. The deuterium atoms $D(p_i)$ have a distribution of momenta $p_1 \ldots p_n$. The electrons e are produced with a distribution of different momenta $q_1, q_2 \ldots q_n$. Its transition rate can be calculated through a n^{th} order perturbation theory as discussed in Phys. Rev. Lett. 52 1184 (1984) and 33, 1336 (1986) cited above and, incorporated herein by reference.

$$\bar{W}_n = \Big(\frac{1}{n!}\Big)^2 \sum_{\substack{\vec{p}_1\ldots\vec{p}_n\\ \vec{q}_1\ldots\vec{p}_n}} N(p_1)\ldots N(p_n)\;2\pi\delta(\Delta E)\big|\langle n\vec{p}',\vec{q}_1\ldots q_n|\,H_I\,(1/\Delta E\;\;H_I)^{n-1}\,|\vec{p}_1\;\ldots\;\vec{p}_n,\;n\vec{k}\rangle\big|^2 \qquad (11)$$

where the bar over w_n indicates it is an average over initial momentum distribution of deuteriums due to finite temperature. Then it can be evaluated to yield

$$\bar{w}_n=(n!)^3 \quad (p_1)^{n-1} \bar{w}_1 Q_n \tag{12}$$

This expression has obvious physical meaning. For each species of coherent bosons, we have an $\sqrt{n!}$ factor due to

$$a_k \ldots a_k \; |n(k)> \; = \; n!\,|o> \tag{13}$$

where a_k is the annihilation operator of bosons with momentum k. Therefore, we expect that the quantum coherent effect of the ions greatly enhances the nuclear fusion rate.

In normal S-matrix scattering, both the time τ and normalization volume V are taken to be infinite $\tau \to \infty$, $V \to \infty$. In order for a laser to work, it is necessary to count the number of final states available. A finite normalization volume as given by the volume of the laser is needed. In the case of producing coherent bosons in a scattering process as considered here, it is further necessary to use a finite time interval τ as given by the interaction time in order to produce a finite number of final states. We here use

$$\tau = 2\pi\delta\ (o) = 1\mu m.$$

There are two species of n coherent bosons: photons and deuterons in (10). An additional n! comes from the bosonic character of the commutator of the Hamiltonian. There are n elementary processes, $\gamma D \to d^+ e$ going on, so that the probability is

proportional to P_1^n or the transition rate is proportional to $P_1^{n-1}\overline{W}_1$. The Q_n comes from the fermionic character of the electron in the final state. The expression for Q_n can be greatly simplified to yield

$$Q_n = e^{-1/4n\,(n-1)\eta'} \tag{14}$$

if the following condition is satisfied:

$$n\eta' < 1 \tag{15}$$

with

$$1/\eta' = \sqrt{V_d V_e}\;(\mu m k_B T)\;/\;(2\pi\tau)\;(|\vec{p} - \vec{k}|) \tag{16}$$

The physical meaning of (16) is that the number of states $1/\eta'$ electrons can occupy cannot be exceeded by the number of electrons n due to fermi statistics. The average transition rate $\overline{W}$ can be recast in the following form:

$$\overline{W}_n = Z^n \overline{W}_1 \tag{17}$$

where Z is approximately given by

$$Z = (n^3/e^3)\;P_1 e^{-\frac{1}{4}n\eta'} \tag{18}$$

where the stirling formula for $n! = (n/e)^n$ is used. The exponential damping factor comes from the fact that no two fermion can occupy the same final state. The critical condition for the instantaneous creation of n strongly coupled or ultimately coherent deuterons is determined by the inequality

$$Z > 1 \tag{19}$$

When $Z<1$, the transition rate for n deuterium to become n coherent deuterons is extremely small because n is a large number $n(>10^{10})$ and Z^n is very small indeed. On the other hand, if $Z>1$, the transition rate for n deuterium to become n strongly coupled

or ultimately coherent deuterons will become very large, and the production can be regarded as instantaneous. The initial condition Z=1 is similar to what occurs in phase transition in condensed matter.

B) <u>Ionizing a Deuterium Atom to Alpha and Gamma Particles to Achieve High Decay Rate Γ</u>

Returning to formula (13) above, it is seen that for every reaction process that involves coherent or strongly coupled bosons, the probability is greatly enhanced by a n! factor. For two deuterons at atomic distance, the fusion rate is 10^{-70}/sec, a very small number indeed. However, if there are say n = 200 coherent deuterons, the rate will be increased at least by a factor $(200/e)^{200} \sim 10^{370}$ which amounts to almost instantaneous fusion or decay of the 200 coherent deuterons with the release of nuclear fusion energy. Normally, nuclear fusion of deuterons is enhanced by increasing the density, or reducing the distance among deuterons by the use of high temperatures and a confinement scheme. However, it is clear that the enhancement of nuclear fusion can come about more easily if strongly coupled or ultimately coherent deuterons are created first. Strongly coupled or ultimately coherent deuterons are favorably produced at low temperature in general instead of requiring the high temperature normally associated with fusion studies. There exists some qualitative differences between the end product of

normal fusion of two deuterons and the decay of coherent deuteron. The two deuterons can fuse in the following ways:

$$d^{+} + d^{+} \rightarrow {}^{3}He + N + 3.25\ MeV \qquad (20)$$

$$\rightarrow t + p + 4\ MeV \qquad (21)$$

$$\rightarrow \gamma + \alpha + 23.6\ MeV \qquad (22)$$

where α = alpha particle, γ = gamma particle, p = pions, N = neutron, t = tritium. Normally (20) and (21) dominate the fusion decay process with 50% each, while the fusion decay into γ and α is an electromagnetic process and is down by a factor of 1/137. As is well known in the art, unstable nuclei decay into 1 of 3 forms. These are alpha (α), beta (β) and gamma (γ). Alpha is clearly a strong reaction. Beta and gamma involve strong reaction and electromagnetic reaction. However, α and γ are both bosons and can be coherent, there are additional n! factor for each coherent boson in the decay product. Hence the dominant decay mode of coherent deuteron is (22) and not (20) and (21). That is, reaction 22 is more likely to occur if the density of bosons with mass is sufficiently high, if these bosons are caused to become coherent or strongly coupled by bombarding them while at low temperature with a high energy short pulse of say photons. The decay products of (20) consist of an odd number of nucleons, which are all fermions.

The formalism as developed above in (1) (2) follows from the phonomenological Hamiltonian for (20) (21) (22) are

$$H_1 = g_1 \int d^3x\, \phi_d \phi_d \phi_\alpha^* A + h.c. \qquad (23)$$

$$H_3 = g_3 \int d^3x\, \phi_d \phi_d \psi_3^* \psi_N^* + h.c. \qquad (24)$$

$$H_2 = g_2 \int d^3x\, \phi_d \phi_d \psi_t^* \psi_p^* + h.c. \qquad (25)$$

with Φ standing for boson quantum field and Ψ for fermion quantum field and the indices refer to the particular particles. Also g = coupling factor, x = integration variable, A = photon and h.c. = Hermitian conjugate. All spins are neglected again. These formulas are essentially the same as (2) above, the nomenclature varying slightly.

(C) Decay Rate of Equations 20 through 22 Compared

Perturbation theory is now used to calculate (22) with (23). For the decay of two coherent deuterons

$$2d^{+}(\vec{0}) \rightarrow \alpha\ (\vec{q}) + \gamma(\vec{k}) \qquad (26)$$

0 = zero momentum
q = momentum of alpha (α)
k = momentum of gamma (γ)

The decay rate becomes

$$\Gamma_1(d) = g_1^2 \frac{2m}{\pi V}\left(1 - \sqrt{\frac{m}{m+E_\alpha}}\right) \qquad (27)$$

where V is the normalization volume of deuterons, m the mass of nucleon of deuteron, and E_α the binding energy of α relative to deuterons. $(=2m_d - m_\alpha)$. (Note: While deuterons are used here, any boson with mass is applicable.)

For the decay of 2n strongly coupled or ultimately coherent deuterons into α and γ, we have:

$$2nd^{+}\ (\vec{0}) \rightarrow n\alpha\ \ (\vec{q}) + n\gamma\ (\vec{k}) \qquad (28)$$

the decay rate is

$$\Gamma\ (\alpha) = \tfrac{1}{2} n!\,(2n)!\ \left(\frac{1}{8}\Gamma_1\ (\alpha)\,\tau\right)^{n-1} \Gamma_1\ (\alpha)\ \ (1+\eta_\alpha)\ \ (1+2\eta_\alpha)$$
$$\cdots\ (1+\ \ (n-1)\,\eta_\alpha) \qquad (29)$$

where the characteristic time τ is $2\pi\delta(0)$, and

$$1/\eta_\alpha = \text{number of quantum states in the final state}$$

$$= \frac{\sqrt{V_\alpha V_\gamma}}{\pi T} \frac{2m\omega^2}{2m+\omega} \qquad \omega = 2\sqrt{m^2+mE_\alpha} - 2m \tag{30}$$

The $(2n)!$ comes from $2n$ coherent deuterons, $(n!)^2$ comes from two coherent bosons α and γ and the η factor is the requirement that the final state α and γ can only go into one quantum state among all available phase space in order to be coherent. $V_\alpha V_\gamma$ are normalization volume of the relevant particles.

There are then two cases depending on the value of $n\eta_\alpha$:

(a) $n\eta_\alpha \gg 1$. The physical meaning is that there are many more particles than the number of states in the final state, so that boson condensation phenomenum can occur easily. The coherent deuterons decay mainly into coherent α and coherent gamma ray. The decay rate is proportional to $(n!)^2\,(2n)!$.

(b) $n\eta_\alpha \ll 1$. There are far less particles than the number of states in the final state. All the particles in the final state have different momenta and are incoherent. The decay rate is proportional to $(n!)\,(2n)!$, one less $(n!)$ factor than the previous coherent case.

Similarly the decay rate of two coherent deuterons into ^3He and neutron as in process (20) is

$$\Gamma_1\,(^3He) = g_3^2\left(3m/8\pi V\right)\sqrt{3mE_3} \tag{31}$$

where g_3^2 can be obtained from the cross section of the scattering of two deuterons

$$d+(\vec{p}_1)+d(\vec{p}_2) \rightarrow {}^3He(\vec{q}) + N(k) \tag{32}$$

with the cross section σ given by

$$\sigma_1 = g_s^2 \frac{3\sqrt{3}m^2}{8\pi|\vec{p}|}\sqrt{\vec{p}^2+mE_3} \tag{33}$$

where $\vec{p}$ is the center mass momentum of the two scattering deuterons and E_3 is the binding energies of ^3He or tritium relative to two deuterons ($2m_d-m_{He}$). That is, $E_3 = 2m_d - m(^3He) - m(N)$. The decay rate of coherent deuterons into helium and neutrons

$$2nd^+(\vec{O}) \rightarrow n^3He + nN \rightarrow nt + nN \tag{34}$$

is then given by

$$\Gamma_n(^3He) = 1/2(n!) \ (2n)!(1/8 \ \Gamma_1 \ (^3He)\tau)^{n-1} \ \Gamma_1 \ (^3He)Q \tag{35}$$

$$Q = (1-\eta_3))1-2\eta_3)\cdots(1-(n-1)\eta_3) \ \Theta \ (1-(n-1)\eta_3) \tag{36}$$

$$1_{/\eta 3} = \sqrt{V_3V_N}/16\pi\tau \quad 3m\sqrt{3mE_3} \tag{37}$$

where the (2n!) comes from the coherent character of the initial deuterons, and there is additional n! due to the commuting properties of the Hamiltonian H_3 to the n^{th} order. The fermi statistics of ^3He and neutron dictates that all final particles cannot occupy the same states. This is shown up in the decrease of phase space as reflected by the $(1-\eta_3)$ factor for first additional fermian pair, and $(1-2\eta_3)$ for the second additional fermion pair to the (n-1) pair. There is no diminishing of phase space for the first pair. The $\frac{1}{\eta_3}$ is again the number of quantum states in the final state.

It is clear from comparing (29) and (35) that $\Gamma_n(\alpha)$ is bigger by at least a $(n!)$. The other fermionic decay mode $2d^+ \rightarrow t+p$ is similar to (17) by replacing only g_3 by g_2 and E_3 by E_t, the binding energy of t relative to 2d $(2m_d-m_t)$. The difference of the fermionic decay mode (35) as compared with the bosonic decay mode (29) is the plus sign in $(1+i\eta)$ is changed to minus sign $(1-i\eta)$, typical in the many statistical factors associated with fermions and bosons.

For the case of non-coherent particles in the final state $(nn_\alpha \ll 1)$, it is clear that the fermionic decay mode of coherent deuterons dominates just because normally fermionic decay mode dominates $\Gamma_1(^3He) \gg \Gamma_1(\alpha)$. To find the enhancement factor due to the coherence of the initial deuterons, one notes that the characteristic time τ is equal to $4/\Gamma_T$ where Γ_T is the total decay width

$$\Gamma_T = \Gamma_n(\alpha) + \Gamma_n(^3He) + \Gamma_n(t) \simeq 2\,\Gamma_n(^3He) \tag{39}$$

Then Eq. (35) can be reduced to yield

$$\Gamma_n(^3He) = n^3/e_3 \quad \Gamma_1(^3He) \tag{40}$$

where stirling formula $n! \simeq (n/e)^n$ is used to reduce the n! factor. The enhancement factor is approximately n^3 over and above whatever the enhancement factor that comes from screening effect in classical strong coupling plasma. It basically comes from quantum statistical nature of coherent particles. For $n = 10^{12}$, $\Gamma_1 1 = 1/\text{sec}$. Γ_n becomes $10^{34}/\text{sec}$ and the release of fusion energy is immediate.

It is also clear the photon γ in (23) and (34) can be replaced by other matter waves such as phonon if the decay of strongly coupled or ultimately coherent deuterons occur inside matter media rather than in a vacuum. Furthermore, the coherent α particles can fuse with the release of additional energy to become coherent ^8Be, which also decays until it reaches the stable nuclei. One in fact gets much larger amounts of nuclear energy from such a cascade decay of strongly coupled or ultimately coherent bosons.

D) Caveat

Returning to formula 10 above, through the incidence of intense or coherent photons or coherent helium atoms or coherent bosons with mass, here deuterium, one may produce coherent charged bosons (nd^+) where d^+ is an ionized deuteron, which will decay to produce nuclear energy. It is in fact possible that the impact of the coherent photons (or helium) on the deuterium which is at low temperature will produce only strongly coupled cold plasma of deuteron ions with coupling Γ>>180. These strongly coupled deuterons will undergo fusion as discussed in my USSN 421601 incorporated herein by reference.

Further, the impact of coherent helium clusters (USSN 169,648 and 231,194 incorporated herein by reference) on deuterium may produce nuclear fusion not only through the mechanism of formula 10 but also as

$$n\,He(p) + D(k) \rightarrow He(p'_1) + \ldots He(p'_n) + D(k'). \qquad (41)$$

In this instance, the deuterium atom gets accelerated from momentum k + k' by the impact of n coherent helium atoms. The high energy deuterium atom will initiate fusion the normal way.

It is possible to create coherent deuterons by coherent helium scattering off solid deuterium at low temperatures. This arises by replacing photons in equation (10) with coherent helium.

$$nHe(k) + D(p_1) + \ldots\ldots D(p_n) \rightarrow nd^+(p') + e^-(q_1) + \ldots\ldots e^-(q) + nHe(k') \quad (42)$$

The helium He(k) needs to have energy k_o at least much larger than the binding energy E_B/n of the deuterium atom:

$$k_o > E_B/n \text{ with } E_B = 13.6 \text{ eV} \quad (43)$$

so that it can ionize it.

Coherent helium atoms with high energy are discussed in US patent application 112,842 (12.10.87), and international application PCT/AU88/00411 (20.10.88) which are incorporated herein by reference.

A still further alternative process in accordance with the invention involves coherent light scattering off crystalline deuteron plasma.

As discussed elsewhere such as in US Patent 103,631 (1.10.87), and International Application PCT/AU88/00383 (30.9.88), incorporated herein by reference, it is possible to create a very cold plasma of deuterons d^+ and electrons. If it is cool enough, the plasma coupling Γ_p defined by

$$\Gamma_p = \frac{\text{potential energy}}{\text{kinetic energy}} = \frac{\alpha}{aT} \qquad (44)$$

$$E_B \sim \frac{\alpha}{a} \sim 2\text{x}10^{-3}\text{eV for } a = 1\mu\text{m} \qquad (45)$$

$$\sim 2\text{x}10^{-2}\text{eV for } a = 0.1\ \mu\text{m} \qquad (46)$$

where α = 1/137 is the fine structure constant; a the average distance between the deuterons in the plasma and T is the temperature; is large

$$\Gamma_p > 180 \qquad (47)$$

we shall have a strongly coupled plasma with crystalline structure. The difference between a solid crystalline plasma and a solid deuterium is that

(i) The distance between deuterons in a crystalline plasma is much larger a=1μm for a density n=10^{12}/cm^3 or a=0.1μm for n=10^{15}/cm^3. For solid deuterium the distance between the deuterons is of atomic scale a~10^{-6}cm.

(ii) The electrons in the cool plasma are free and can reach higher temperature, whereas the electrons in a solid deuterium are bound to each individual nucleus.

(iii) The binding energy of a crystalline plasma is between the positive charged deuteron with neutralizing background from electrons and is much smaller.

The value in the above formula (46) is a much lower value than the binding energy of electrons in a deuterium atom. Hence, it is possible to use a photon with much lower energy to knock out the deuterons from a crystalline lattice position to become a free deuteron since if the deuterium atoms are in a strongly

coupled plasma their E_B is lower than if the atoms are in a solid:

$$n\gamma(k) + d(p_1)+\ldots d(p_n) + \{d(p_{n+1})+\ldots d(p_{n+\ell})\}$$
$$\rightarrow nd(p') + \{d(p'_{n+1})\ldots d(p'_{n+\ell})\} -$$
$$(\text{with } k_o > E_B) \tag{48}$$

The curly bracket {d} denotes the deuterons that remain in the crystalline lattice in the plasma and they recoil with some distribution momentum so that the overall energy momentum is conserved in e.g. (48).

The advantage of (48) is that the lasers that produce k_o~1eV are quite common and therefore easy to find while the coherent light of (10) requires k_o>13.6eV. Lasers of this energy are difficult to obtain.

In the above we use charged deuterons as an example. It is possible to substitute d^+ with any other atomic nuclei or ionized atoms which are bosons, without altering the process. If they are atomic nuclei bosons, and if they are made strongly coupled or ultimately coherent by processes similar to those herein discussed, then they will also decay (or fuse) to produce fusion energy. Furthermore, the coherent photon (10) can be replaced by a very strong but very short pulse of photons, say from a synchrotron radiation. These noncoherent photons will not create coherent deuterons, but will create strongly coupled deuterons which can also fuse/decay to release nuclear energy. Recent construction of synchrotron with energy of electrons 2 to 7 GeV that will emit synchrotron radiation in the ultraviolet region,

i.e. E >13.6eV has made this possible. The duration of the light pulse must be so short that the fusion rate is bigger than the recombination rate between deuterons and electrons ($d^+ + e^- \rightarrow D + \gamma$).

E) Theory Summation

The electromagnetic decay of a deuteron beam is particularly interesting for the following reasons:

(a) Of all decays, the electromagnetic decay of interaction (22) releases the maximum energy. Because the helium nucleus γ or ^4He is more tightly bound than ^3He or tritium t, the amount of energy converted to kinetic energy of the final decay products in electromagnetic decay is more than that from the strong decay (20). The decay $^4He + \gamma$ releases six to eight times more energy than the decay of t+H or ^3He+n. (where t=tritium and n=neutron)

(b) The electromagnetic decay product consists of a photon and He without a neutron. Neutrons are released in strong decays. Because of the strong penetrating power of neutrons through matter, it is difficult to provide adequate shield and the utilization of these in nuclear energy devices may make nuclear energy more costly and complicated. On the contrary, the energy released in electromagnetic decay is mainly endowed in high energy coherent gamma ray, and the rest in charged particles ^4He. The high energy gamma ray can easily be converted into an electron shower by lead plates.

The energy of the photon is given by

$$\omega = (4m_d^2 - m_{He}^2)/4m_d = 23.5 \text{ MeV} \qquad (49)$$

The α particle (Helium nucleus) only takes away 0.3% of the total energy.

(c) The electromagnetic decay of coherent deuteron is a source of coherent helium nucleus (or α) and coherent high energy gamma ray of 23.5 MeV. A 23.5 MeV gamma ray laser is particularly useful to the community of quantum optics researchers. The above consideration also holds if the incident beam is composed of coherent bosons, such as coherent He. Thus if photon γ is replaced by bosons having mass the foregoing still applies.

IV. Description of Invention Apparatus and Specific Examples

This invention relates to a method and apparatus utilizing the decay of a strongly coupled or ultimately coherent boson such as strongly coupled or ultimately coherent deuterons.

We are interested in all of the decays of modes 20 through 22, and in particular, in reaction (22) above which may be broadly seen as $A + A \rightarrow B + \gamma + E$ where the 'A' comprises coherent bosons, 'B' denotes the fusion product of 'A'; 'γ' denotes one or more photons; and E is the released energy.

The invention also provides apparatus for carrying out the invention comprising means for generating the strongly coupled or coherent boson and allowing the strongly coupled nuclei to undergo strong decay and electromagnetic decay to produce energy.

In the Drawings

The invention is further described by way of example only with reference to the accompanying drawings in which:

Figure 1 is a diagrammatic cross section of an apparatus constructed in accordance with the invention.

Figure 2 shows the minimum number of photons required to satisfy the critical transition Z=1 for temperatures T=2° to 10° K. The five curves are evaluated for different energies of the photon E =14, 16,18,20,22 eV from bottom to top;

Figure 3 shows the values of $n\eta$ at temperatures between 2° to 10° K for different energies of photon E =14,16,18,20,22, eV from bottom to top.

Detailed Description of a Preferred Embodiment of the Invention

The process thus far described is effective to create coherent charged deuterons causing coherent light to be incident on solid deuterium which is at low temperature. In another words, a cold plasma is being used here.

Figure 1

Referring now to Figure 1, there is shown therein a cross sectional view of a fusion device for producing nuclear energy by the described process.

The device 10 shown comprises a cryostat 12 containing liquid helium in an interior chamber 14 surrounded by a liquid helium containing jacket 16. At a lower part of the cryostat,

there is provided a vacuum chamber 18 having therein a container 20 containing deuterium pellets which are maintained at liquid helium temperature by virtue of being adjacent to the liquid nitrogen in chamber 14. The pellets used may be of any form known in the art such as in the form of deuterium oxide. They should be solid and may be frozen. The deuterium pellet should be at room temperature, but preferably below, such as the temperature of liquid helium. A gate 22 is provided in a floor of the container 20 to permit release of deuterium pellets in a known manner one at a time from the gate to fall within the vacuum chamber 18. The vacuum chamber 18 has a window 26 formed in a side wall thereof and laser light of energy of at least one joule from a source 30 is directed via a focussing lens 32 through the window to be brought to a focus at a location 36 within the vacuum chamber.

The deuterium pellets as they fall within the chamber 18 remain at low temperature of room temperature or below and are kept at that temperature by the liquid helium jacket and the vacuum into which they pass. At location 36 the laser light is directed in a pulse onto the pellet to generate energy and gamma rays by the process above described. The pellet density should be at least $2.2\times10^{22}/cm^3$. In order that the deuterium atoms in solid can be treated as a pure state, the pulse duration of the laser must be short as compared with the period of phonon vibrations so that dephasing of the atoms will not occur. At a temperature $T = 10°K$, the laser pulse must be very short with

$\tau \ll \frac{1}{K_B T} \sim 3$ pico seconds.

The laser is connected to the gate such that upon release of a pellet the laser is triggered to pulse once against the pellet, this occurring at point 36. The pulse must be a pico second or less and 1 joule or higher. The location 36 is surrounded by lead shielding to absorb the gamma rays and other radiation which may be generated. At various locations as desired, the lead shielding, which may be in the form of sheeting, is interfaced with one or more silicon cell layers whereby the gamma rays directed thereto through the lead shielding are converted to electric energy directly by photo electric effects. Thus, output electricity may be generated directly from the silicon cells such as at the terminals 42, 44 shown. The lead shielding is illustrated at, for example, 52 in the drawing and the silicon at 54.

The laser 30 may be operated in pulsed fashion to direct one pulse of light at one pellet of deuterium as it falls to location 36 in the vacuum. Thus, the pulsings may be synchronous with the operation of door 22. A vacuum chamber is not mandatory but advisable.

Of course, although apparatus 10 is shown as utilizing released photons to directly produce electricity by photoelectric interaction, this is not essential and energy released may be otherwise applied such as to produce heated liquid (for example steam) which is used for example to produce electricity by conventional means such as turbines.

The process whereby the energy is released from the interaction of the deuteron pellets and the laser light is described in formula (22). The deuterons in the described pellets are rendered strongly coupled or ultimately coherent by the incidence of the laser beam thereon, and it is the strongly coupled or ultimately coherent deuterons which decay as above described to give off the gamma rays.

A further example will be enlightening.

Used is a deuterium pellet with volume

$$V_D=V_d=V_e=100\ \mu m \times 100\ \mu m \times 100\ \mu m$$

Where V_D= normalization volume of deuterium

V_d= normalization volume of deuteron

V_e= normalization volume of electron

The pellet is at about liquid helium temperature. Photons from a laser (30), thus coherent photons, are pulsed onto each pellet individually while each pellet is in a vacuum chamber. The energy of the laser is one joule or greater, its pulse length is 100 cm and the area of the deuterium pellet where pellet and laser pulse coincide is 100μm x 100 μm.

$$V = 100\ \mu m \times 100\ \mu m \times 100\ cm$$

The energy of the photon ranges from

$$E = \quad = 14 \text{ to } 22eV$$

The coupling constant g is calculated using the ionization cross section $\sigma_i = 10^{-17}cm^2$. N. Wainfan, W.C. Walker, and G.L. Weissler, Phys. Rev. 99,542 (1955), incorporated herein by reference. The ionization cross section is considerably bigger

than the elastic cross section at these energies. There are, therefore, no other competing channels. From Z=1, we can calculate the minimum number of photon n that is needed for temperature $T=1^{\circ}$ to 10° K. It is in the range of $n\sim12^{12}$ as shown in Figure 2, which means an energy of a μJ per pulse, which is not stringent at all. The value of $n\eta'$ calculated and shown in Figure 3 and is smaller than 1, as required.

One last example of creating an infinitely strongly coupled cold plasma with coherent deuterons is set forth. Making use of earlier equations 14, 16 and 18, a laser pulse with photon energy 14 to 22eV, a pulse length less than 0.3 psec, and a number of photons $n > 10^{12}$ with a deuterium pellet of size (100μm) at $T = 1^{\circ}$ to 10° K can satisfy the critical condition $Z \geq 1$. When the critical condition is reached, the transition rate is greatly enhanced because of the enormous power of Z^{n-1} . All the deuterium atoms will be instantaneously ionized to produce coherent deuterons with infinite coupling. These coherent deuterons will also decay subsequently to yield nuclear fusion energy.

We conclude the parameters required to produce strongly coupled or ultimately coherent deuterons instantaneously are within reach of present experimental situations. The immediate use of strongly coupled or ultimately coherent deuterons is that they will fuse/decay to release an enormous amount of nuclear energy. The above scheme utilizing cold infinitely strong coupling plasma may be a new way to achieve nuclear fusion.

Claims

1. A method for creating coherent bosons having mass (a^+), said method comprising:

shining a coherent beam of bosons (b) in a short intense pulse of high energy on a solid pellet of bosons having mass (B) in accordance with the following formulae and critical condition:

$$nb\,(\vec{k}) + B\,(\vec{p}\,) + \ldots .\, B\,(\vec{p}_n) \rightarrow na^+\,(p) + e^-\,(\vec{q}\,) + \ldots e^-\,(\vec{q}\,)$$

where k, p, q, are momenta; a is the nucleus of B, the boson atom with mass having a maxwellian distribution in momentum at temperature T; and n is the number of particles;

the transition rate (w) being

$$w = Z^{n-1}\,\bar{w}_1$$

where the following is the critical condition

$$Z = (n^3 / (4e^3))\,\bar{w}_1 \tau e^{-m\eta'/4}$$

$$1/\eta' = V\mu m_b\, k_B T / (2\pi\tau) \left| \vec{p}\,' - \vec{k} \right|$$

when Z is greater than or equal to 1;

μm_b being the masses of electrons and boson atoms with mass; w being the maxwellian average of transition rate of a single boson in said boson beam ionizing a single boson atom with mass; being the interaction time; and V being the normalization volume.

2. The method of claim 1 wherein said bosons with mass (B) are deuterium.

3. The method of claims 1 or 2 wherein said boson beam (b) is a beam of helium clusters.

4. The method of claims 1 or 3 wherein said boson beam (b) is a laser light.

5. The method of claims 1 or 2 wherein said boson beam (b) is a beam of helium.

6. The method of claim 3 wherein said photon energy is 14 to 22 eV, the pulse length is less than 0.3 pico seconds; the number of photons is greater than 10^{12} with a deuterium pellet of approximate size (100 um); the temperature is 1° to 10° kelvin.

7. A method of forming strongly coupled plasma and/or coherent bosons with mass (a^{+}) in a cold plasma by cooling bosons with mass in a solid (a) at least to room temperature and shining thereon in a short, high intensity pulse so as not to cause said plasma to become hot, a beam of coherent bosons or intense boson beam (b), the energy of said bosons (b) being greater than the ionization energy of said bosons with mass (a), said method resulting in the release of nuclear energy from the fusion/decay of the strongly coupled plasma and/or coherent bosons with mass (a).

8. The method of claim 7 wherein said shining occurs in a vacuum chamber and wherein said pulse must be short as compared with the period of phonon vibrations so that the dephasing of the atoms of said bosons with mass (a) is prevented.

9. The method of claim 8 wherein at a temperature of 10 degrees kelvin the pulse must be short with λ being very much smaller than $(1/(k_B T))$ which is approximately equal to three pico seconds where λ is the wave length of said boson beam (b).

10. The method of any of claims 7 through 9 wherein the reaction between the bosons with mass (a) and the beam of bosons (b) is an electromagnetic decay reaction according to $A + A \rightarrow C + \gamma + E$ where "A" are the strongly coupled to coherent bosons (a,b); "C" is the fusion product of "A"; γ is one or more bosons; and "E" is released energy.

11. The method of any of claims 7 through 9 wherein the reaction between the bosons with mass (a) and the beam of bosons (b) is a strong decay reaction according to $A + A \rightarrow C + D + E$ where "A" are the strongly coupled to coherent bosons (a^+); "C" and "D" are the fusion product of "A"; and "E" is released energy.

12. The method of claim 7 wherein said coherent bosons with mass (a) is deuterium and said beam of coherent bosons or intense beam

(b) is comprised of photons, said photon energy being greater than the binding energy of the atoms of the deuterium, the pulse length being less than 0.3 pico seconds; the number of photons being greater than 10^{12} with said deuterium being in a solid pellet of approximate size (100 um); the temperature of said pellet being 1° to 10° kelvin at the time said pulse of photons strikes said deuterium pellet to form said strongly coupled plasma and/or coherent bosons with mass (a^{+}).

13. The method of claim 7 wherein said boson beam (b) is a beam of photons from an ultraviolet source.

14. A method of forming a cold plasma of at least strongly coupled to coherent bosons with mass, said method comprising:
shining an intense to coherent beam of bosons in a short, high energy pulse on a solid containing bosons with mass, said beam having an energy exceeding the binding energy of said bosons with mass, said pulse time not exceeding the period of phonon energies of said bosons with mass, the decay occurring upon the incidence of said pulse of bosons on said boson with mass being

$$2na^{+}(0) \rightarrow nA + nN$$

where "a^{+}" are the bosons with mass; n is the number of particles; A and N is the fusion product; 0 is zero momentum.

15. A method of releasing nuclear fusion energy comprising impacting coherent bosons with mass such as coherent helium

clusters on bosons with mass such as deuterium.

16. A method of releasing nuclear fusion energy comprising impacting bosons with mass with a very short very strong pulse of bosons as might be emitted by a synchrotron, said strength of said pulse having to be greater than the binding energy of said boson with mass, said length of said pulse having to be less than $1/k_BT$.

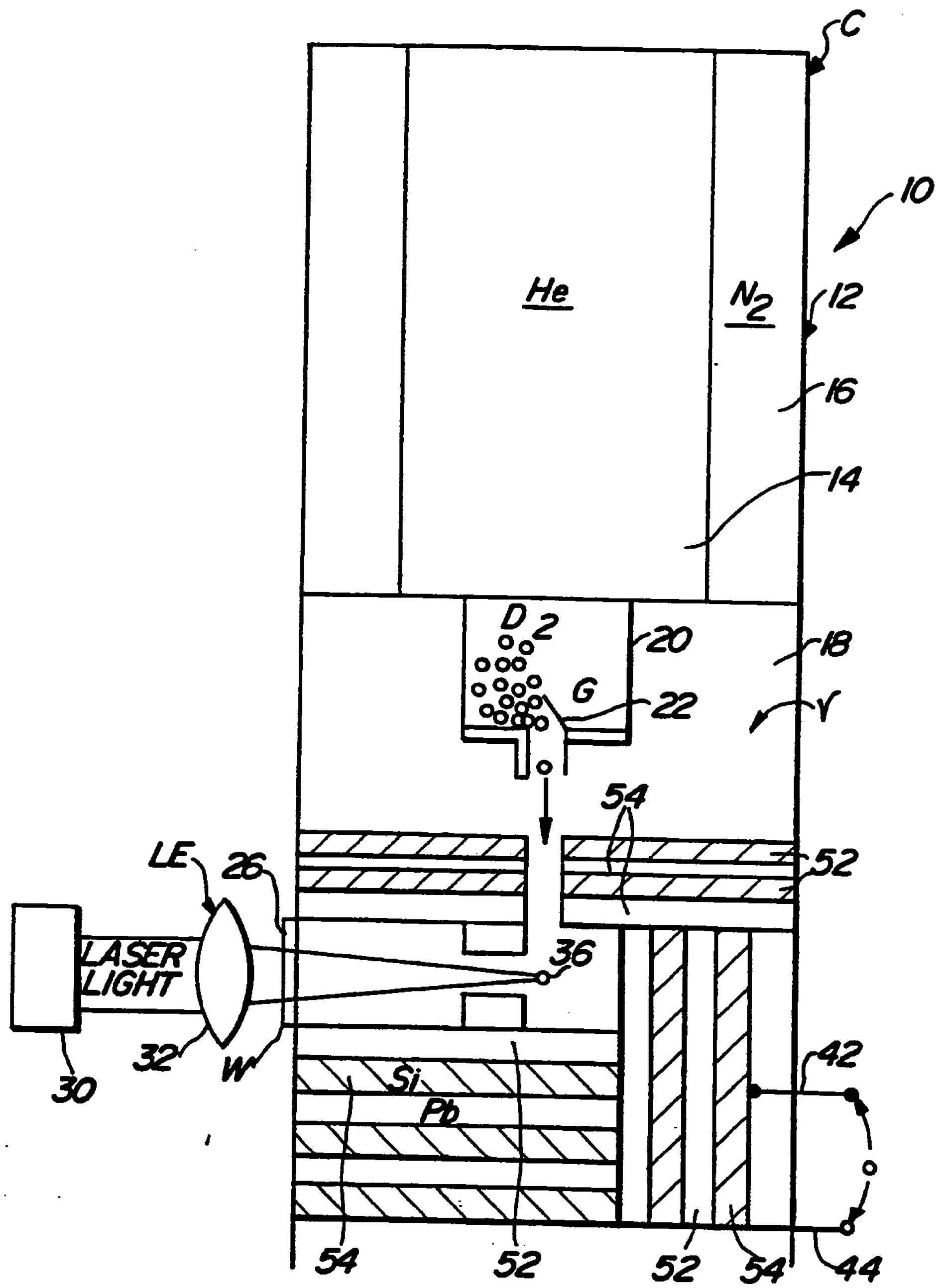

C
10
He
N_2
12
16
14
D 2
20
18
G
22
Y
54
52
LE
26
LASER LIGHT
36
30
32
W
Si
Pb
42
54
52
52
54
44

FIG. 1

FIG. 2

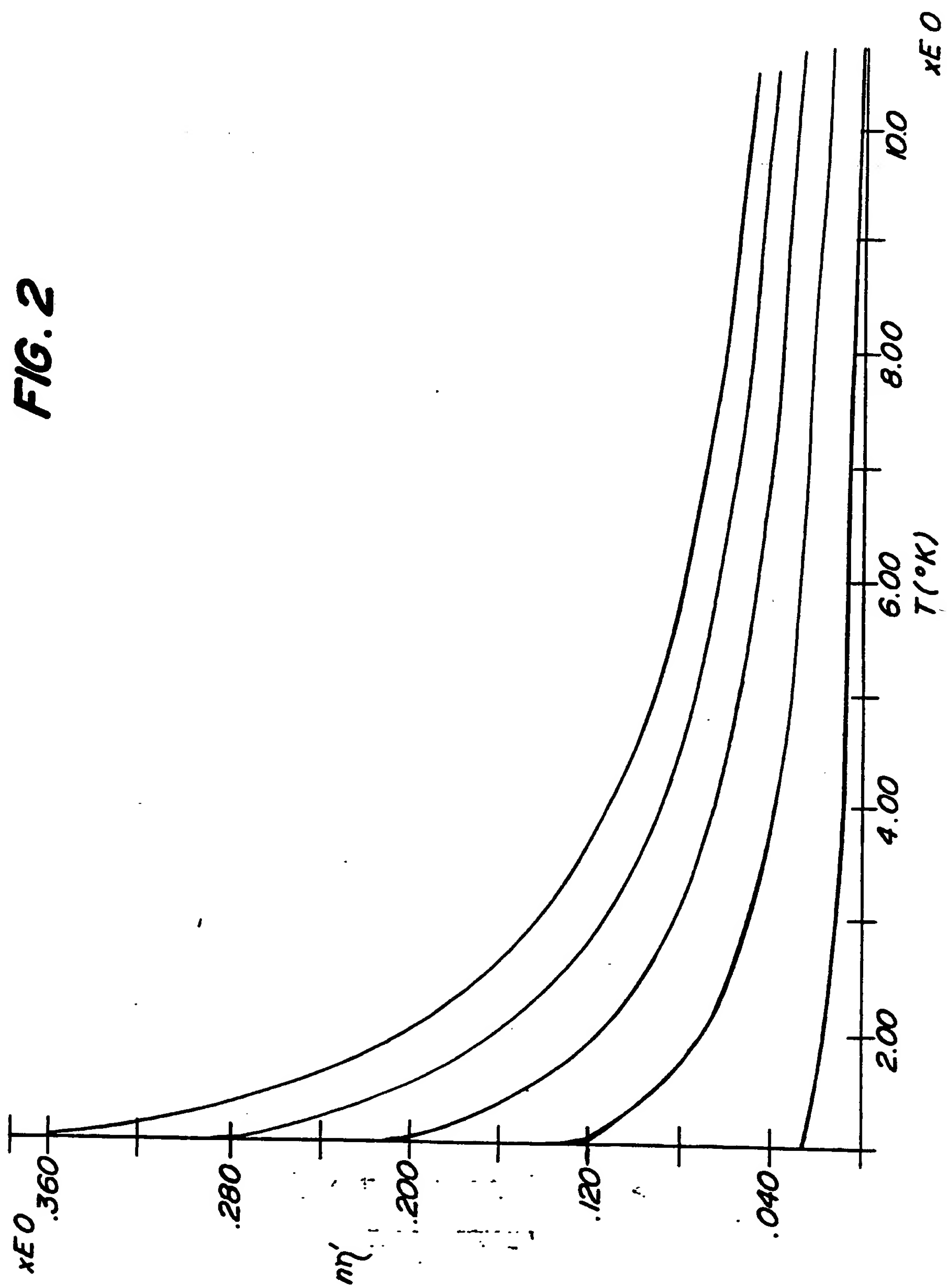
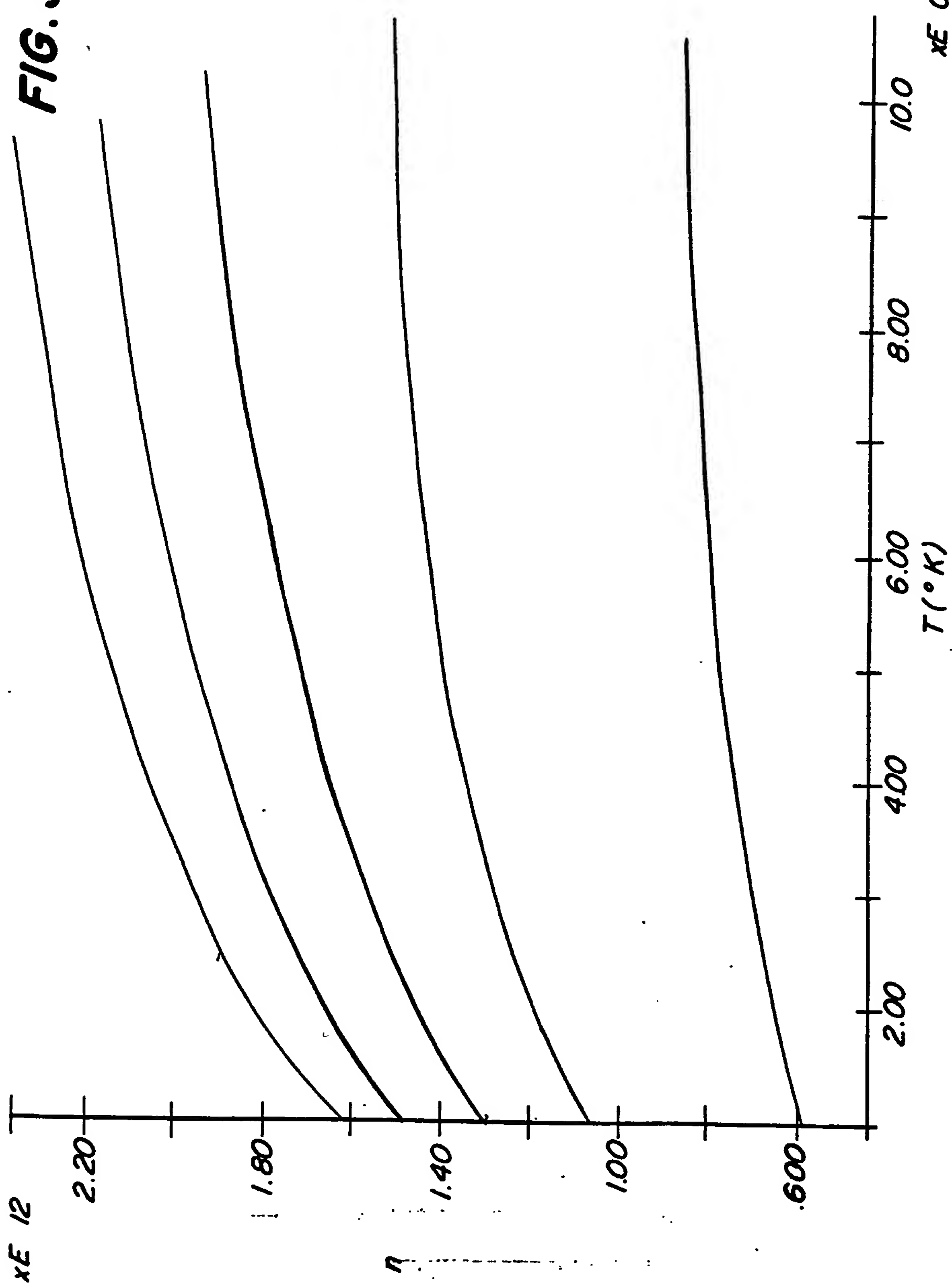


FIG. 3



INTERNATIONAL SEARCH REPORT

International Application No PCT/US90/01990

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC(5): G21B 1/00
U.S. CL.: 376/100, 103, 106

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
U.S. CL.	376/100, 103-108, 120

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
X	WO, A, W087/00681 (LO) 29 January 1987, See pages 2,3,5,10,14-20,26 (particularyl lines 30-34), 27,28,39.	1,2,4,5,7,10, 11,14,15
Y	WO, A, W087/00681 (LO) 29 January 1987.	3,6,9,12-13,16
Y	J. Vac. Sci. Technol., vol. 20, No.4, (April 1982), See pages 1375-1380 (particularly the first column on page 1378), BIEG ET AL.	1,3,5,15
Y	New Scientist (28 February 1980), pages 653, 654.	13
Y	PPPL-2516 (May 1988), "High Power Picosecond Laser System at 248NM", pages 1-21, TIGHE ET AL.	13
Y	US, A, 4,755,344 (FRIEDMAN ET AL.) 05 July 1988.	3,15
Y	US, A, 4,597,933 (RIPIN ET AL.) 01 July 1986, See col. 7, lines 25-37.	13,16
A	US, A, 3,808,432 (ASHKIN) 30 April 1974.	

* Special categories of cited documents: [15]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
28 AUGUST 1990	24 SEP 1990
International Searching Authority [1]	**Signature of Authorized Officer** [20]
ISA/US	for NGUYEN NGOC-HO INTERNATIONAL DIVISION HARVEY E. BEHREND

Form PCT/ISA/210 (second sheet) (May 1986)

International Application No. PCT/US90/01990

FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

Y	US, A, 3,489,645 (DAIBER ET AL.) 13 January 1970, See cols. 1,6,11.	1,2,4,6-12,14
P,A	US, A, 4,875,213 (LO) 17 October 1989.	
P,A	US, A, 4,926,436 (LO) 15 May 1990.	
P,A	US, A, 4,940,893 (LO) 10 July 1990.	

V. ☐ OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE [1]

This international search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1. ☐ Claim numbers .. , because they relate to subject matter [1] not required to be searched by this Authority, namely:

2. ☐ Claim numbers .... , because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out [1], specifically:

3. ☐ Claim numbers ________, because they are dependent claims not drafted in accordance with the second and third sentences of PCT Rule 6.4(a).

VI. ☐ OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING [2]

This International Searching Authority found multiple inventions in this international application as follows:

I. The specie of a beam of coherent helium (CLAIMS 1-3,5,7-11,14,15).

II. The specie of a coherent photon beam (claims 1,2,3,6-12,14).

III. The specie of non-coherent photon beam (claims 7-14,16).

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.

2. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:

3. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:

4. ☐ As all searchable claims could be searched without effort justifying an additional fee, the International Searching Authority did not invite payment of any additional fee.

Remark on Protest

☒ The additional search fees were accompanied by applicant's protest.

☐ No protest accompanied the payment of additional search fees.